RE: RFI FOA # 2529

Hydrogen Demonstrations in support of DOE's Hydrogen Energy Earthshot " 1 - 1 - 1 "

1. **Accelerate the production, storage, delivery, and end use of clean, affordable hydrogen;**
2. **Viable hydrogen demonstration and deployment projects that enable clean hydrogen; production, infrastructure and end use**
3. **Enable a net-zero carbon emissions economy by 2050.**

Categories:

- **Regional Hydrogen Production, Resources, and Infrastructure**
- **End Users for Hydrogen in the Region, Cost, and Value Proposition**
- **Greenhouse Gas and Pollutant Emissions Reduction Potential**
- **Diversity, Equity, Inclusion (DEI), Jobs, and Environmental Justice**
- **Science and Innovation Needs and Challenges**
- **Additional Information**

6 July 21

HFTO Colleagues,

Renewables-source "green" H2 will be profitable and important for total global de-carbonization and de-GHG-emission only at regional-to-continental scales. Hydrogen Energy Earthshot "1 - 1 - 1" will require new, high-purity, gaseous H2 (GH2) underground pipeline systems -- both repurposed extant pipelines plus new-builds -- for gathering, transmission, "free" storage by pipelines "packing", and distribution. These pipelines must be built of linepipe immune to hydrogen embrittlement (HE) and hydrogen corrosion cracking (HCC), to safely accommodate the frequent, large pressure variations inflicted upon the pipeline systems by variable energy resources (VER's) such as wind and solar.

But such ambitious plans are now hampered by great uncertainty about suitable linepipe, valves, meters, compressors, and other system components, and total high-purity GH2 pipeline systems designs and operating conditions. Furthermore, we are in danger of over dependence upon, and over-investment in, the electricity Grid, which might result in delaying progress toward (3), above, by suboptimal policies for allocation of CAPEX and markets between Grid and H2 infrastructures. Research by SA, M. Lyubovsky, et al showed that GH2 pipeline transmission costs less, per unit of energy-distance, at large scale. [1] See Figure 2.

Therefore, we need to immediately launch collaborative imagination, innovation, research and modeling, design, and financing for an International Renewable Hydrogen Transmission Demonstration Facility (IRHTDF), perhaps via IPHE, as described in my panel presentation at the 2010 NHA annual meeting, Long Beach: https://vimeo.com/209160500 " Begin Now: Design and Build a Renewables-Source Hydrogen Transmission Pipeline Pilot Plant "

[1] *Relative Cost of Long-Distance Energy Transmission by Electricity vs. Gaseous and Liquid Fuels;* SA, et al, 2019 Daniel DeSantis, Brian D. James, Cassidy Houchins, Genevieve Saur, and Maxim Lyubovsky,

At least US, Germany, Canada, Australia, and Japan should be primary national partners. For example:

> **North Rhine-Westphalia (NRW) Ministry of Economic Affairs, Innovation, Digitalisation, and Energy: In a Nov 2020 "hydrogen roadmap", among NRW's many targets set for 2025, the state wants to host 120 kilometers (km) of Germany's planned 500 km of hydrogen pipelines that would be connected to the nation's first "supra-regional" hydrogen lines.**

The IRHTDF would be a complete, scale model, renewables-source system, probably 30 - 60 km long, of:

- Diverse CO2-emission-free energy sources
- Diverse customers: markets and offtakers
- Gathering and transmission underground pipelines made of novel linepipe immune to HE, HCC
- Multiple pipeline entry and takeoff points
- Avoiding midline GH2 compression, to discover strategies for "compressorless" transmission [2]
- Oxygen byproduct delivery to biomass gasification plants adjacent to electrolyzers

The IRHTDF's purposes:

- Initiate design practice for high-purity GH2 pipeline systems for regional-to-continental scales; pipeline system design optimization via hydraulic modeling
- Assist resolution of how GH2 pipelines, especially interstate, are regulated: FERC, or other
- Verify safety and economy of novel linepipe materials and components in VER service: prevent accidents and overly-ambitious expectations for GH2 pipeline systems, if IRHTDF results so indicate
- Motivate and initiate an R&D&D program for novel linepipe materials immune to HE, HCC [3]
- Develop GH2 pipeline safety standards, materials and devices standards, and best practices
- Discover transmission energy losses; establish design practice for midline compression, if required, including avoidance thereof
- Enable electricity Grid-based vs GH2 pipeline-based systems comparison, hypothesis testing
- Prevent over-dependence upon, and over-investment in, the electricity Grid
- Estimate performance, costs, and benefit / cost ratios for multi-GW-scale pipeline systems
- Estimate CAPEX and OPEX savings for off-Grid wind and PV plants dedicated to delivering all their captured energy as GH2 fuel via pipeline, eliminating costly components for Grid delivery
- Engage in and benefit from worldwide participation and results dissemination
- A lighthouse demonstration: gaseous hydrogen (GH2) pipeline pilot plant, a complete modest-scale system to enable scale-up, if results are encouraging
- Persuade the public and policymakers of the pervasive potential of Hydrogen in achieving humanity's goal of a net-zero Carbon and GHG- emissions-free economy by 2050

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[2] *Compressorless Hydrogen Transmission Pipelines Deliver Large-scale Stranded Renewable Energy at Competitive Cost*; W. Leighty, J. Holloway, R. Merer, B. Somerday, C. San Marchi, G. Keith, D. White. Poster, World Gas Conference 2006, Amsterdam Download poster: http://www.leightyfoundation.org/wp-content/uploads/whec16-lyon/WHEC16-Compressorless-LoRes.pdf Download paper: http://www.leightyfoundation.org/wp-content/uploads/wgc-amsterdam/WGC-Abstract310.pdf

[3] Alaska Applied Sciences, Inc. submitted a Concept Paper for ARPA-E 2021 "OPEN" FOA # 2459 - 3339, for this linepipe R&D&D: *Grid Security: Low-cost, GWh-scale, High-purity, Gaseous Hydrogen (GH2) Storage & Transmission System: "Packed" Pipeline Storage for VER Sources, On- or Off-Grid, via Novel Polymer-Nonferrous-Metal Hybrid Linepipe Immune to Hydrogen Embrittlement (HE)*

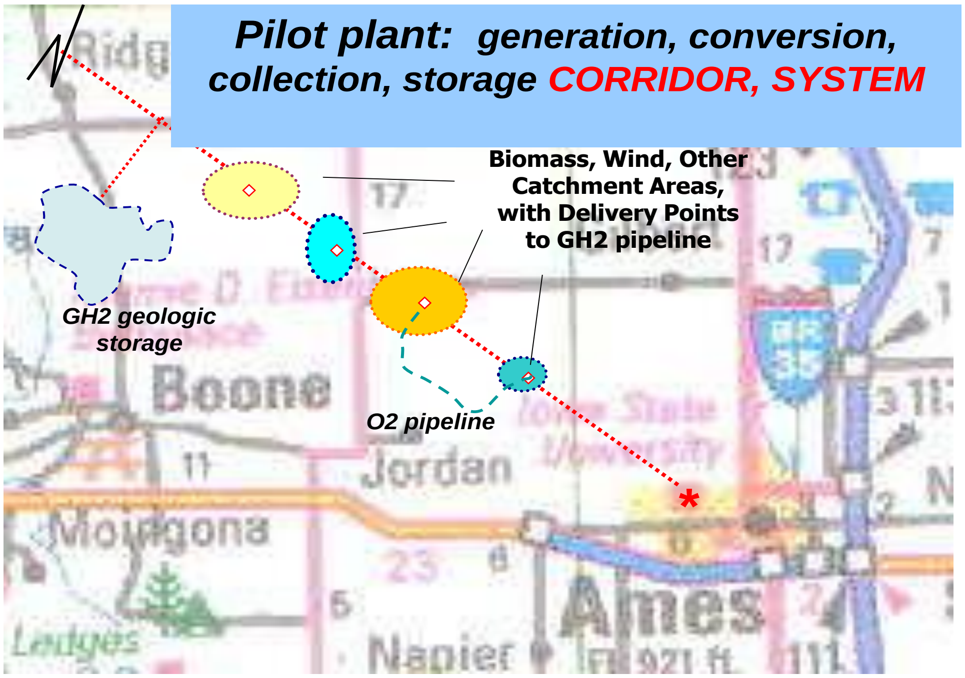

Figure 1. The International Renewable Hydrogen Transmission Demonstration Facility (IRHTDF) proof-of-concept pilot plant, which might be best implemented in USA in IA, CO, WA, TX, or / and CA: complete, synergistic, optimized GH2 CO2-emission-free energy system based upon a gaseous H2 (GH2) pipeline system. Geologic storage is probably not attractive in IA. A continental-scale pipeline network would connect to hundreds of storage caverns in GOM domal salt for annual-scale firming storage.

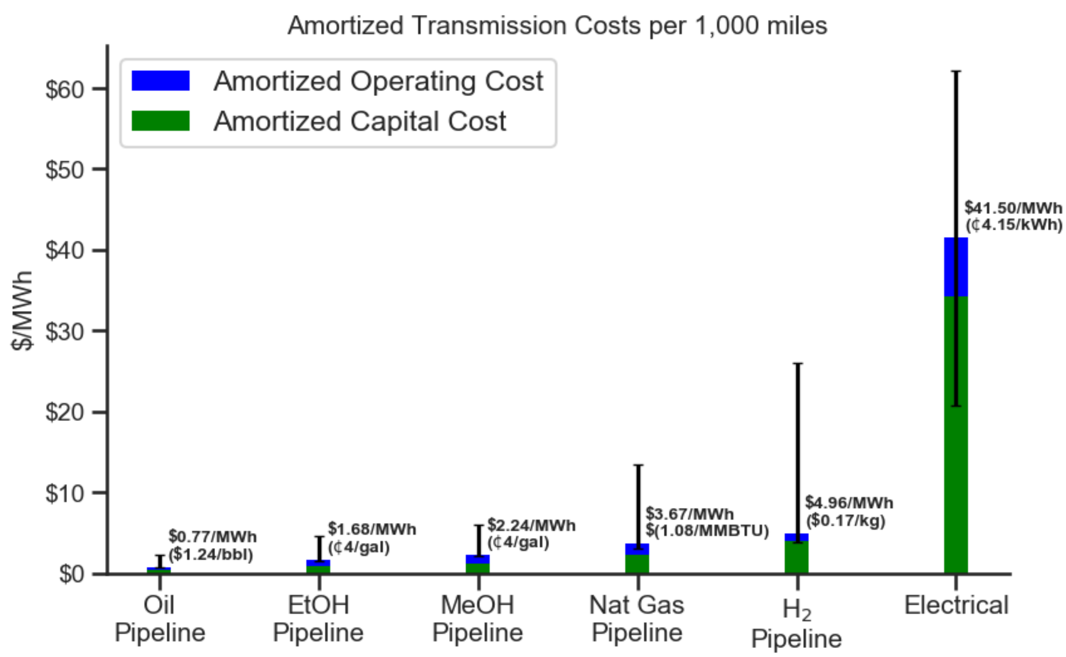

Figure 2. From SA, Lyubovsky, et al, 2019 Capacity of a 20" GH2 pipeline, without midline compression, 800 km long, at 100 bar MAOP input, 30 bar delivery at customer or city gate, is > 1,000 Mt / day GH2.

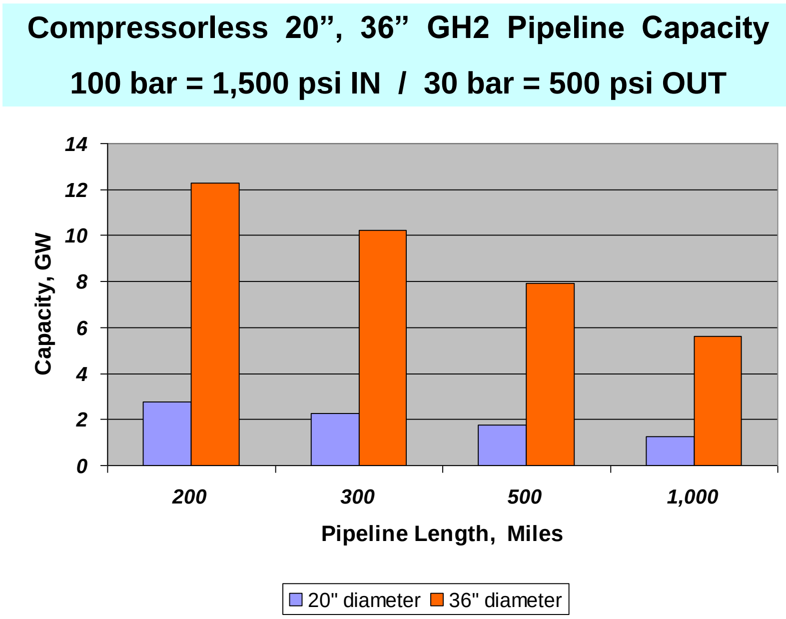

Figure 3. GH2 pipelines have large continuous power capacity (GW, Mt GH2 per day) without midline compression, because of low viscosity and high mobility of H2 vis-a-vis CH4 molecules, for example. We bear the friction losses rather than invest in midline compression in this economic optimization. Based on hydraulic modeling by Jeff Holloway. See footnote 2.

Figure 4. At IRHTDF destination, high-purity GH2 is distributed for transportation and stationary CHP fuel and for industrial feedstocks, via extant and / or new underground pipelines immune to HE, HCC.

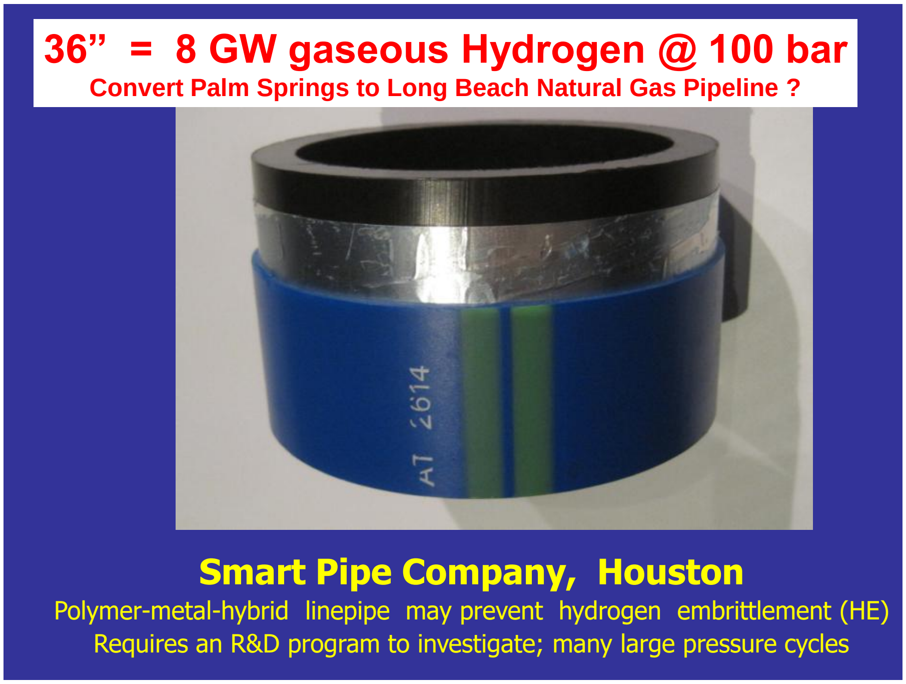

Figure 5. A Smart Pipe Company concept sample, circa 2005, but not intended for, nor tested for, high-purity GH2 in VER service. HDPE core. A thin layer of Cu or Al in pipe wall is the H2 permeation barrier: might be a spiral-wrapped foil with laser-welded seams or metal spray deposition. FRP overwrap (not shown here) accepts maximum allowed operating pressure (MAOP).

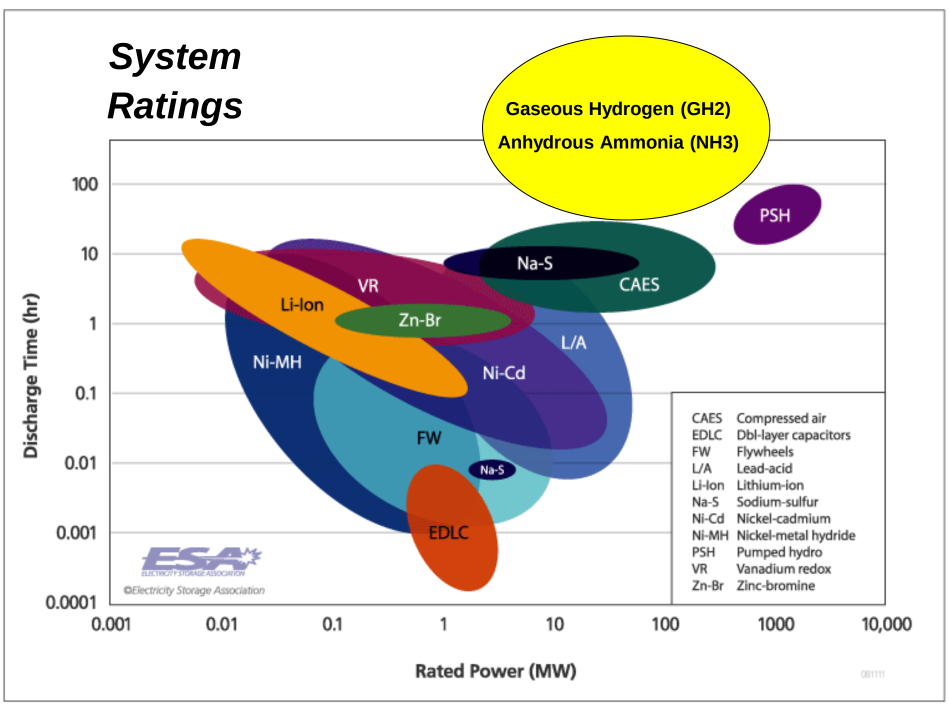

Figure 6. "Packing" GH2 pipelines to MAOP, unpacking to ~ 1/3 MAOP, provides "free" energy storage, while connecting CO2-emission-free VER's to very-low-cost, annual-scale, firming storage in Gulf Of Mexico (GOM) region domal salt caverns, perhaps also in bedded salt caverns in other regions in USA.

CATEGORY: Regional Hydrogen Production, Resources, and Infrastructure

1. Please describe specific ideal regions to support a hydrogen demonstration project which have the necessary resources available for clean hydrogen production and infrastructure ...

I believe these are good candidate sites for the IRHTDF system demonstration. I cannot detail for each of the various attributed specified in the RFI FOA:

1. Central Iowa: Fort Dodge area to Ames, about 60 - 80 km, to supply all this region's product green H2 to the Iowa State Univ campus, including Ames Laboratory, plus some retail or truck or bus fleet fueling stations. An underground pipeline system cross-country through farmland will be minimally disruptive and probably easier to permit than elsewhere. IA wind and solar resource intensities are good, for synergistic harvest. PV on north ditch sides of county roads feed the pipeline, for zero ag loss.

2. Douglas County Public Utility District, central WA, has surplus Columbia River hydro, to pipeline as GH2 west from Wenatchee to south Seattle (Kent, Renton), about 210 km, or to GH2 fueling stations along I-90. Gov Inslee signed SB 5588 on 17 Apr 19, allowing PUD's to produce renewable H2 for sale. The Douglas County Public Utility District is spending around $20 million to build its renewable hydrogen production plant on the east bank of the Columbia River north of Wenatchee. [4]

3. Destination University of Colorado at Pueblo, on the NE side of Pueblo, bringing wind and PV source energy from diverse sources NE of Pueblo to operate vehicles and buildings on campus, plus public and fleet retail fuel stations. Coordinate with Xcel and perhaps other energy or utility companies to share ROW or other infrastructure from energetic wind and solar resources east of Pueblo. The IRHTDF could be easily extended to deliver to a future large GH2 pipeline connecting most CO, NM demand, on I-25.

4. Central TX, bringing wind and PV source energy to a target city or oil refinery or ammonia plant. TX may have out-of-service or abandoned pipelines of various types that may be relined or otherwise modified for high-purity, VER-source, GH2 service to attractive pioneering markets. New-build pipelines may also be profitable, made of novel linepipe immune to HE, HCC.

5. Palm Springs, CA and San Gorgonio Pass, sending wind + PV GH2 to Inland Empire, Long Beach, or LA. A 16" Dominion pipeline, former Questar "Southern Trails", passes through West Palm Springs to central Long Beach, but the pipeline is now out-of-service and incomplete, but may be of IRHTDF demonstration value. Permitting is often difficult in CA.

CATEGORY: Science and Innovation Needs and Challenges

9. Please provide input on any fundamental science, basic or applied research, and innovation needs and challenges that may be required for, or be informed by, the demonstration projects. In addition, please identify scientific user facilities or computational tools that would provide the required innovations or resolve the remaining challenges.

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[4] https://www.nwpb.org/2021/03/09/wenatchee-area-hydrogen-production-plant-signals-renewed-interest-in-alternative-fuel/

a. Pipeline system design for GH2 networks at > 100 bar MAOP optimized for regional-to-continental scale, assuming several technical and economic optimization cases:

(i) At regional-to-continental scale, GH2 will be primary vector for gathering, transmission, annual-scale firming storage, and distribution of CO2-emission-free energy from VER's;

(ii) Electricity infrastructure will be limited to "first and last" km, or several km, of the total C-free energy; GH2 and NH3 pipelines and very-low-cost storage everywhere between.

b. Linepipe design and manufacture R&D: For dedicated, high-purity, underground gaseous hydrogen (GH2) pipeline networks practically immune to HE and HCC, in VER service where:

(i) Large and frequent pressure fluctuations will be inflicted upon the pipeline system by time-varying sources such as wind and solar;

(ii) The pipeline system will be used as "free" energy storage by "packing" the pipeline to maximum allowed operating pressure (MAOP) when source outputs are high, unpacking to ~ 1/3 MAOP when outputs are low.

Apparent promising novel linepipe candidates, for immunity to HE, HCC are:

1. Polymer-nonferrous-metal hybrid, following research at ORNL in 2000's on "polymer-metal tubing" . Thin nonferrous metal H2 permeation barrier mid-pipe wall, and FRP overwrap to achieve desired MAOP rating. Desirable feature: on-site manufacture in continuous process, in any length, to minimize connections or couplings, for:

- Pulling into extant pipelines, relining, to rehab and repurpose them for GH2 and VER service;
- New-build, direct placement in trench, from mobile factory moving along the trench.

Apparent candidate manufacturers: Smart Pipe Company, NOV Fiberspar, Houston. Relevant IP may exist, limiting early participation and competition among manufacturers.

On 5 April 21 Alaska Applied Sciences, Inc. submitted a Concept Paper for ARPA-E 2021 "OPEN" FOA # 2459 - 3339, for this linepipe R&D&D: *Grid Security: Low-cost, GWh-scale, High-purity, Gaseous Hydrogen (GH2) Storage & Transmission System: "Packed" Pipeline Storage for VER Sources, On- or Off-Grid, via Novel Polymer-Nonferrous-Metal Hybrid Linepipe Immune to Hydrogen Embrittlement (HE)*

2. Composite reinforced linepipe (CRLP) introduced for experimental service by TransCanada in early 2000's. Mild, low-alloy steel core pipe overwrapped with FRP capable of MAOP. Inspected weld joints are overwrapped with FRP to achieve MAOP. Overpressure hydro-testing expands and deforms steel pipe upon exterior FRP, so that FRP bears the tension load: steel flex and expansion is minimized.

10. Are there systems integration or prototyping facilities available or needed that could benefit the project and de-risk large-scale deployment? Please describe any testing facilities that could be used or are required.

The IRHTDF itself becomes the "systems integration and prototyping facility". The IRHTDF's purpose is to "de-risk large scale deployment".

Site selection for the IRHTDF will be important, and may provoke international competition. Since the IRHTDF would be an international collaboration, all partners' facilities should be considered. I don't know how the five candidate sites, above, are equipped for such facilities; survey, analysis required.

Next steps for the IRHTDF:

1. Gather collaborators: countries, businesses, NPO's, R&D and test organizations and universities
2. Well-funded FOA's by HFTO and / or ARPA-E in to accelerate TRL in the above R&D areas
3. Select international support organization: IPHE ?
4. Catalog and analyze potential sites -- perhaps for several IRHTDF's

The H2 community also should beware that when we are able to bore "deep enough, cheap enough" to profitably reach it, deep hot dry rock geothermal (DHDRG) energy, which is generally ubiquitous on Earth -- -- will probably displace: [5]

- Wind, solar, and other distant VER's at high-intensity resources;
- The need for transmission and storage of large-scale VER from distant plants, via any means;
- The need for an IRHTDF to facilitate building GH2 pipeline networks at regional-to-continental scale because most worldwide electricity, thermal energy, and much of industrial feedstocks will be produced by DHDRG, the ultimate in distributed energy resources (DER's) .

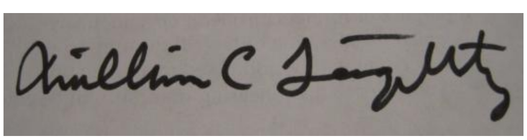
The H2 community should therefore track DHDRG access via novel boring technologies . [6] The Leighty Foundation has modestly co-funded two H2 systems research projects; Bill Leighty was advisor to both:

- Pacific Northwest Renewable Hydrogen Action Plan [7] by Center for Sustainable Infrastructure and Renewables Hydrogen Alliance (RHA)
- A Systems Analysis of the Future Role of Hydrogen in a Carbon-neutral California, before 2050, by Institute for Transportation Studies (ITS), UC Davis

Bill Leighty's advisory memo to the two conference organizers is also attached to the RFI response email. It includes the hypotheses discussed in this memo, including DHDRG.

But without ubiquitous profitable DGDRG energy, achieving "H2@Scale", " 1 - 1 - 1 " , and NZE by 2050 will require in USA a new, safe, dedicated, high-purity, underground, GH2 pipeline system at regional-to-continental scale. We should begin its realization now. The IRHTDF, perhaps via IPHE, would be a good start. FCHEA, CHBC, RHA, GHC, and many other NGO's should be invited to help.

Thank you for your consideration.



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[5] http://www.leightyfoundation.org/wp-content/uploads/GRC-Poster-223BillLeighty-E.pdf
[6] Pivot2020 conference, 15-17 July 2020 See: 15 July, 11:45 "The Future of Drilling: Non-conventional Concepts"
[7] https://www.sustaininfrastructure.org/renewable-hydrogen-action-plan

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Solar and wind grid system value in the United States: The effect of transmission congestion, generation profiles, and curtailment

Dev Millstein, Ryan Wiser, Andrew D. Mills, Mark Bolinger, Joachim Seel, Seongeun Jeong
Open AccessPublished:June 21, 2021DOI:https://doi.org/10.1016/j.joule.2021.05.009

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David Mercer, director of Technology – Energy Solutions at Fluor Canada.

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